Estimation and Visualization of Seafloor Uncertainty

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LONG-TERM GOALS

The long-term goal of the Capturing Uncertainty DRI is to assess and characterize uncertainty in the tactical naval environment. As part of the Seafloor Variability team, the focus of our effort is to develop approaches to characterizing uncertainty associated with measurements of bathymetry and other seafloor properties that are important for sonar performance predictions. We are also developing innovative methods to visualize this uncertainty.

SCIENTIFIC OBJECTIVES

The specific scientific objectives of the UNH team are:

1- To develop automated approaches for quantifying the errors and uncertainty associated with the collection of modern multibeam sonar bathymetry. Bathymetry is a fundamental input into most range dependent sonar performance predictions.

2- To develop approaches for assessing the uncertainty associated with historical bathymetric data sets.

3- To develop and deploy techniques to accurately measure, *in situ*, key physical and acoustical properties of seafloor sediments in selective shelf environments so that we may have real estimates of the spatial scales of variability of these parameters (shared with Geoclutter and Mine Burial DRIs).

4- To develop sophisticated 3-D visualization techniques that can convey the captured uncertainty in a useful and intuitive manner.

APPROACH

The research tasks we describe are part of a larger effort (the Seabed Variability Team) that in turn feeds into the work of the DRI teams. The interconnections amongst the individual research efforts are described in the report of team leader Holland.

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14. ABSTRACT

The long-term goal of the Capturing Uncertainty DRI is to assess and characterize uncertainty in the tactical naval environment. As part of the Seafloor Variability team, the focus of our effort is to develop approaches to characterizing uncertainty associated with measurements of bathymetry and other seafloor properties that are important for sonar performance predictions. We are also developing innovative methods to visualize this uncertainty.

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Quantify errors and uncertainty associated with seafloor bathymetry:

The topography of the seafloor is a significant driver in interaction and propagation models. The most common source of data about this factor is echosounder measurements, and in modern situations, multibeam echosounders. However, current processing schemes for multibeam data take little account of the uncertainty involved in the measurements, implying that each measurement retained is 'exact'. This is at best misleading, since each depth reported is imputed from measurements which are all uncertain to some degree, and which correspond to an uncertain oceanographic environment. Our approach is to estimate the errors associated with each sounding collected, and then utilize the augmented measurements to track uncertainty through the processing method, resulting in a bathymetric grid model that reports co-located estimates of depth and uncertainty as a unified data pair. We have implemented these ideas in an algorithm we call CUBE (Concurrent Uncertainty and Bathymetry Estimator). A CUBEd dataset provides not only a robust automatic estimate of bathymetry, but also a measure of posterior variance for this estimate, an indicator of problem areas in the survey, and an estimate of CUBE's confidence that these problems have been reliably resolved. The depth/uncertainty grid pair can then be used for further analysis, including for example generation of Monte Carlo ensembles for propagation modeling.

Many bathymetric products are compilations of a number of prior surveys that may span a number of years, or even decades (depending on the location). Hence, the compilation may contain a number of different depth measuring instruments and navigation systems. We have developed a method to estimate the uncertainty associated with such compilations based on a Monte Carlo simulation of expected experimental variability given worst-case estimates of the various devices involved in the composite dataset (Jakobsson, *et al*., in press, 2001). Examination of the variation of the predicted bathymetry generated by the Monte Carlo approach allows us to estimate the uncertainty associated with the final gridded product (i.e., that which is used for further modeling). This produces an important auxiliary data product to inform interpretation of the main bathymetric product.

In situ measurement of key acoustic properties:

In support of another ONR DRI (Geoclutter) we have developed, built, and deployed a relatively inexpensive, robust, ship-deployable device (**ISSAP –** ***In situ*** **S**ound **S**peed and **A**ttenuation **P**robe) for making very accurate measurements of sound speed, attenuation and porosity, in near-surface sediments (Mayer et al, 2002). The **ISSAP** uses four 2.54 cm (diameter) by 30 cm long probes that are inserted 15 cm into the seafloor by 250 kg of reaction weight attached by armored coaxial cable to a free-swinging inner frame within a protective outer tripod. The probes operate at frequencies of either 65 or 100 kHz. An onboard computer and topside electronics control the paths selected and the number of measurements per path. A typical deployment involves measurements across five paths including both long (30 cm) and short (20 cm) paths. In addition to the acoustic and resistivity probes, the ISSAP also has a color video camera that provides imagery of the seafloor and the probes as they penetrate, an altimeter to independently monitor height off the bottom, and temperature, pressure, pitch, roll, and heading sensors to monitor the stability and orientation of the platform. The system makes multiple measurements of *in situ* properties by simply "pogo-ing" on the bottom, and can thus cover a relatively large area of the seafloor in a short period of time. It therefore addresses directly the question of the spatial variability of key seafloor sediment properties. The system has been deployed in several shelf regions of relevance to the Uncertainty DRI.

Visualization of uncertainty:

We continue to explore modes of visualizing this uncertainty (both 2 and 3-D) within the context of the geospatial information (thus the importance of the depth-uncertainty pairs), striving to find the optimal way of presenting key information to the user in the most intuitive manner possible. In the course of this work we will take advantage of the developments of the UNH Data Visualization Lab combining modern high-end, low-cost, graphics boards with a sophisticated interactive 3-D environment that allows us to explore the use of color, shading, draping, transparency and perhaps even stereo or pixel motion, as means of simultaneously presenting both the underlying data and the uncertainties associated with it.

WORK COMPLETED:

Quantify errors and uncertainty associated with seafloor bathymetry:

The basic algorithm for CUBE has undergone significant development and validation during the reporting period. CUBE has now been tested on Simrad EM300/1000/1002/3000 systems, Reson 8101/8125 systems, and on Elac 1180s. Datasets from Portsmouth Harbor, NH, the Gulf of Mexico, the Nootka Fracture Zone (Juan de Fuca plate, Vancouver Island Shelf), Gray's Reef NMS, Woods Hole, MA and Snow Passage and Valdez Narrows, AK have been successfully processed, totaling several billion soundings, spread over 123 ship-days of multibeam survey and depth ranges from shoreline to 2800m. CUBE is being verified against current hydrographic practice before transitioning to NOAA and NAVO in the course of the next year.
The modeling of errors associated with historic bathymetric data sets was developed through the application to two test data sets – one from the Arctic (where the data base is composed of multiple data sources from a wide range of nations, organizations, and platforms) and one from a local area (Great Bay, N.H.) which has had multiple generations of NOAA (or its predecessor – the Coast and Geodetic Survey) of surveys. The Great Bay dataset is currently being augmented by a modern multibeam echosounder data set collected in June 2002.

In situ measurement of key acoustic properties:

The ISSAP was deployed in the GEOCLUTTER area off New Jersey on the *R/V Cape Henlopen* between 30 July and 5 August, 2001 and in the Martha's Vineyard Mine Burial area in August of 2002. The system performed flawlessly recovering water column and sediment data at 99 stations selected to represent a range of seafloor backscatter types over an area of approximately 1300 sq. km.in the GEOCLUTTER area and 87 stations at the Mine Burial site. More than 100,000 discrete measurements and more than 60 Gigabytes of data have been collected as well as more than 40 hours of video.

Visualization of uncertainty:

We have explored a number of approaches to visualizing uncertainty through our work with CUBE and the historical bathymetric data model. Examples of these are in figures 1 and 2.

RESULTS

Quantify errors and uncertainty associated with seafloor bathymetry:

An example dataset from CUBE, figure 1a shows the use in a shallow-water hydrographic dataset (data: dual-head Reson 8125 MBES from Portsmouth Harbor, NH, courtesy of SAIC, Inc. and the Common Dataset for the Second International Conference on High-Resolution Survey in Shallow Water, http://www.ccom.unh.edu/ shallow/shallowsurvey.htm). The figure shows the estimated 95% posterior CI for the associated bathymetry color-coded over the most likely bathymetry estimate. In addition to this augmented data set, the algorithm is fast: this dataset consists of approximately 210×10^6 depth measurements collected over three days, and was processed in approximately 90 min. to the figure shown. Figure 1b shows the same algorithm applied to Simrad EM300 data gathered from the R/V *Thomas G Thompson* off Vancouver Island in May 2002, using the same color-coding scheme (data courtesy of Dr. J. Delaney and Dr. D. Kelley, University of Washington, and the Neptune-Keck Mapping Project (Cruise TN146), http://www.neptune.washington.edu). Here, the estimated uncertainty highlights features that are covered poorly by the MBES and hence should be interpreted with more caution.

The Arctic Ocean dataset, figure 2, highlights a number of themes in our work, including visualization of uncertainty (in this case color coded over the estimated mean bathymetry, with hot colors implying higher uncertainty). It was also used to determine that the 'seamounts' indicated in the diagram were poorly determined by the available data (in the sense that the magnitude of the predicted uncertainty was of the same order as the depth difference to the background seafloor in the area). These proved to be the product of an undetected echosounder error in the original dataset, a fact confirmed by a subsequent survey by the R/V *Polarstern*.

In situ measurement of key acoustic properties:

Over a 1300 sq km area off the N.J. shelf, the sound speed in the sediment varied from 1524 m/s to 1801 m/s and attenuation ranged from 10 to 71.3 dB/m at 65 kHz. Looking at the spatial scales of variability, sound speed varyied over 200 – 300 m/s and attenuation varied by about 60 dB/m over length scales of 10's of kms; sound speed varied by about 100 m/s and attenuation by about 25 dB/m over spatial scales of less than 1 km and sound speed varied by about 5 m/s and attenuation by about 3 dB/m over spatial scales of less than 1 m (except where there were discrete shells or cobbles in the path). These measurements provide the fundamental basis upon which the statistical abstractions of other team members are based. We also continue to explore the use of seafloor backscatter measurements for remotely determining these scales of variability.

IMPACT/APPLICATIONS

The systematic modeling of bathymetric uncertainty can provide bathymetric data sets with well-established error bounds that can then be propagated into sonar performance predictions and used to better understand potential sources of error within the model. Advanced visualization techniques allow us to develop techniques for transmitting uncertainty information to the tactical naval situation. The ability to rapidly and very accurately measure *in situ* acoustic and physical properties provides a direct measure of the spatial scales of variability in key areas and ground-truth for subsequent statistical models that may be valuable in predicting spatial scales of variability.

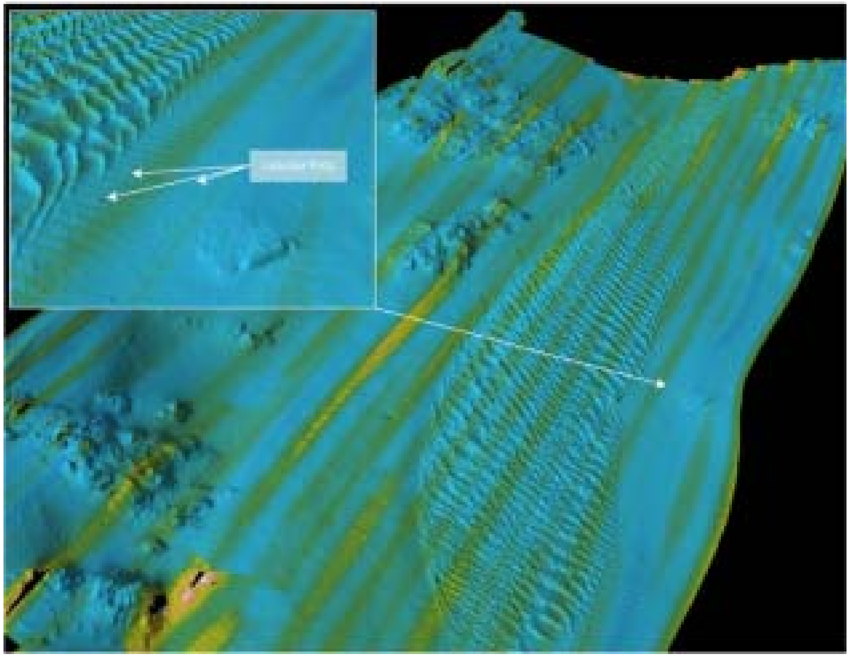

Figure 1a: Rendering of the Portsmouth Harbor Common Data Set utilizing the Reson 8125 MBES Survey. Uncertainty is color-coded over the estimated bathymetry with hotter colors representing higher uncertainty. Note retention of subtle bathymetric details such as the strings of lobster pots shown in the inset.

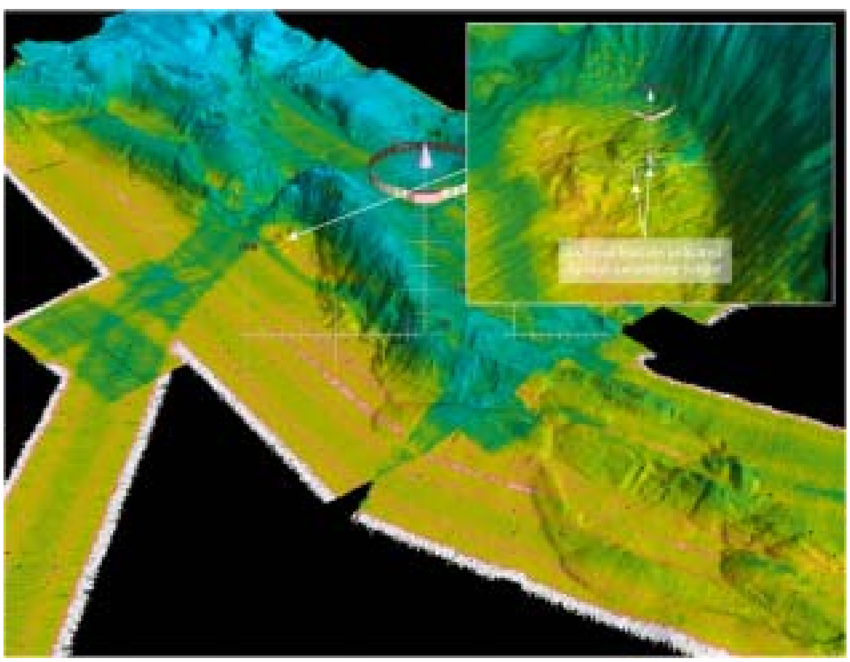

Figure 1b: Simrad EM300 data in the Nootka Fracture Zone, showing estimated posterior uncertainty overlaid on estimated bathymetry. Uncertainty is color-coded so that hotter colors represent higher uncertainty, and the transition to white indicates a 95% posterior confidence interval higher than 30m (depth at this level is approximately 2800 m).

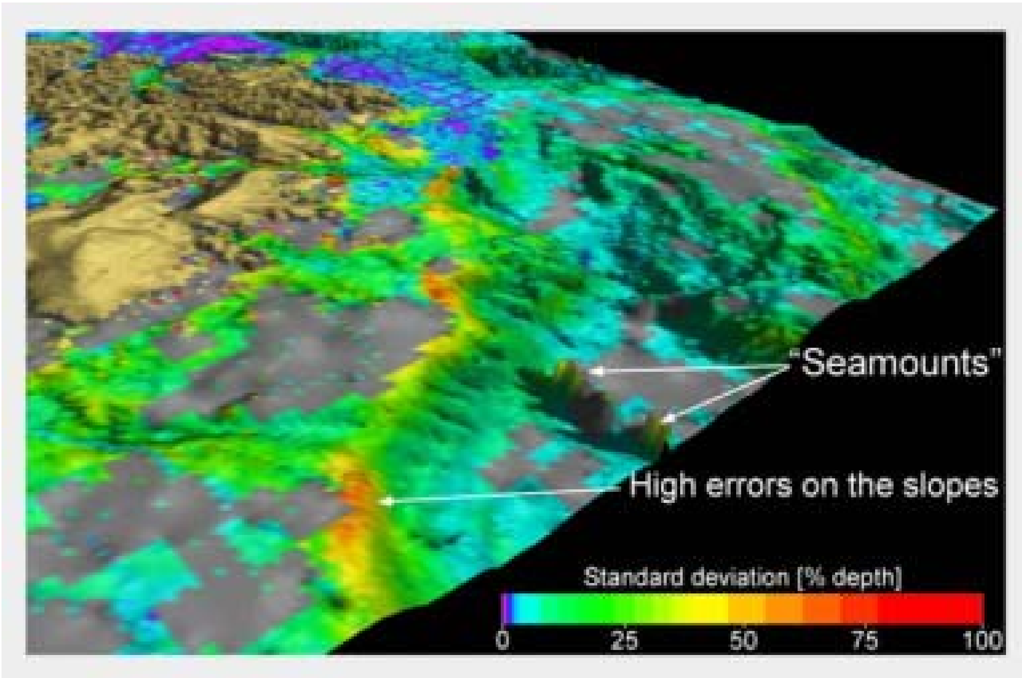

Figure 2: 3D-image, showing the estimated standard deviation as a percentage of the depth draped on the IBCAO bathymetry. The error estimate shows clearly that significant errors are associated with the seamounts. A later survey revealed that these seamounts did not exist.

TRANSITIONS

The CUBE approach to multibeam data processing is being transitioned to both NAVO and NOAA.

RELATED PROJECTS

GEOCLUTTER, Mine Burial DRI

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